

QRS waveforms in right and left bundle-branch aberration*

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SUMMARY The electrocardiographic and vectorcardiographic features of right and left bundle-branch aberration were investigated in 32 patients during programmed electrical stimulation of the heart. Various types of aberration were seen, the right bundle-branch being affected to different degrees in 22 patients and the left in six; four patients developed right and left bundle-branch block at different times. Three of the patients who developed right bundle-branch block also showed loss of the first 40 ms anterior QRS forces, especially the second 20 ms; all also developed combined left and right ventricular conduction defects. Six other patients with right bundle-branch aberration, however, showed loss of QRS forces during the second 20 ms with preservation of the first 20 ms, in the absence of left ventricular conduction defects. Six patients showed anterior increases of the first 40 ms QRS forces, four also having additional left ventricular conduction defects.

The magnitude of the tangential velocity of inscription of the first 20 (and first 40) ms spatial QRS forces was unaffected by right bundle-branch aberration. In only four of the 26 patients with right bundle-branch aberration was less than 70 per cent of the QRS loop directed anteriorly. In all but one of these patients, however, the first 40 ms QRS forces were rotated in a counterclockwise direction even if the later forces inscribed a predominantly clockwise QRS loop in the horizontal plane.

Identification of the abnormalities produced by left and right aberrant conduction clarifies the positive features of ventricular arrhythmias. Furthermore, alteration of the first 40 ms QRS forces in right bundle-branch block will influence the ability to diagnose myocardial infarction accurately on the electrocardiogram.

Although right and left bundle-branch block are common there is little information about these disorders in patients without other cardiac abnormalities. While it is uncommon to record normal electrocardiograms before and after the development of bundle-branch block, whether occurring spontaneously^{1,2} or during cardiac catheterisation,^{3,4} it is only from the features seen in such patients that one can confirm the electrocardiographic criteria for bundle-branch block.

It is well established that left bundle-branch block affects the electrocardiographic diagnosis of both anterior and inferior infarction,⁵ but the picture is less clear with right bundle-branch block.^{6,7} Sandler and Marriott⁸ have stressed the value of a monophasic R wave or an Rsr' in V1 in ventricular arrhythmias, in contrast to an rSR' in right bundle-

branch aberration; these features may be the result of anterior direction of the QRS loop, sometimes with clockwise rotation. Since such a QRS loop has also been described in right bundle-branch block (type B)⁴ it is important to establish how often such QRS loops are seen in right bundle-branch aberration as well as to seek characteristic features of the vectorcardiogram in this conduction defect. As there may be difficulty in the differentiation of ventricular arrhythmias from supraventricular arrhythmias complicated by left bundle-branch aberration we have also studied the latter defect.

Methods

Programmed stimulation of the heart was used to induce atrial and ventricular extrasystoles and rate dependent aberration as well as supraventricular tachycardia with aberration. Routine electro-

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physiological investigation was performed together with vectorcardiographic recordings in 43 patients to elucidate the nature of their arrhythmias. Three recording wires were inserted percutaneously through one or both femoral veins by the Seldinger technique and passed to the right side of the heart; one was positioned in the right atrium, one at the apex of the right ventricle, and one opposite the tricuspid valve, close to the bundle of His.⁹ Orthogonal Frank lead electrocardiograms were recorded both with a Hewlett-Packard 1301B 3 channel electrocardiograph and an analogue magnetic tape recorder (Racal Thermionic Store 7). The tapes were played back through a PDP 12 laboratory computer and all complexes were displayed. Satisfactory complexes were selected and stored with cursor determination of the onset and offset. From these digital data the frontal and horizontal plane vectorcardiograms were printed out with a Complot DP1 digital XY plotter; the points were plotted at 4 ms intervals.¹⁰ The magnitude of tangential velocity of QRS inscription was calculated between each 4 ms point in the frontal and horizontal planes and in three dimensions. Average figures for the first and second 20 ms have subsequently been described as the tangential QRS velocity. The computer also constructed scalar spatial electrocardiograms.

Because the terms complete and incomplete bundle-branch block have been criticised¹¹ we followed the classification of Witham¹² in which first degree bundle-branch block indicates a QRS duration of 120 ms or less, second degree a QRS duration between 120 ms and 150 ms, and third degree a QRS greater than 150 ms. The degree of right bundle-branch aberration in 13 patients with basal partial conduction defects was based on this classification. Witham has also suggested an alternative classification based on the normal QRS duration known for the patient concerned¹²: thus in first degree right bundle-branch block the QRS is prolonged by less than 30 ms in the affected complex, in second degree block additional QRS prolongation is between 30 and 50 ms. We have refined the accuracy of such measurements with our intracardiac recordings and have followed the second classification in the remaining 19 patients who initially had no conduction defects. Right and left bundle-branch blocks were diagnosed according to the criteria of Witham¹² and lesser left ventricular conduction defects often called hemiblocks were described according to established criteria.^{4 13 14}

Results

Forty-three patients were studied of whom 32

developed aberration; 22 had right bundle-branch aberration (without left bundle-branch aberration), six left bundle-branch aberration (without right bundle-branch aberration), and four both right and left bundle-branch aberration at different times. Of the 32 patients, only one patient had a left ventricular conduction defect during sinus rhythm (pronounced left axis deviation) but 10 patients had incomplete right bundle-branch block of the basal QRS; one patient had old inferior infarction, and one had congestive cardiomyopathy with T wave changes in leads I and V3 to V6.

In nine, right bundle-branch aberration was induced by atrial extrastimuli, and atrial fibrillation occurred at the beginning of or during supra-ventricular tachycardia; in five this conduction defect was induced by atrial extrastimuli, supra-ventricular tachycardia, and atrial pacing; in the remaining 12 aberration only occurred after wire manipulation, atrial extrastimuli, or atrial pacing. The type of aberration seen was unrelated to the method of induction. Sixteen patients without any block of the basic QRS developed third degree right bundle aberration; lesser degrees were also seen at other times in 15 of these patients. The remaining 10 patients with right bundle-branch aberration included two with apparent complete right bundle-branch block of the basal QRS, but who developed increasing right bundle-branch aberration with atrial extrastimuli, as well as eight patients with varying grades of first and second degree right bundle-branch block.

The typical pattern of right bundle-branch aberration is shown in Fig. 1. The counterclockwise rotation of the initial 40 ms forces of the QRS was preserved in all but one patient. The most consistent feature of the lesser degrees of aberration was deviation of the terminal forces to the right and either anteriorly or slightly posteriorly; there was variable delay in the terminal forces which were more often superior than inferior. As the degree of right bundle-branch aberration increased so did the terminal delay which was always anterior; because midzone posterior forces were lost the QRS loop was predominantly anterior in the horizontal plane and the middle part of the loop tended to cross the efferent limb increasingly to the left and anteriorly (Fig. 2). Eventually the posterior forces were totally lost and the loop was anterior (> 90%) in all but five patients; in only four patients with third degree block was less than 70 per cent of the loop anterior and in only two of these patients was less than 50 per cent of the QRS loop anterior. In all patients the tangential velocities of inscription of the initial and second 20 ms QRS forces were the same as those of the normal QRS loop. Usually

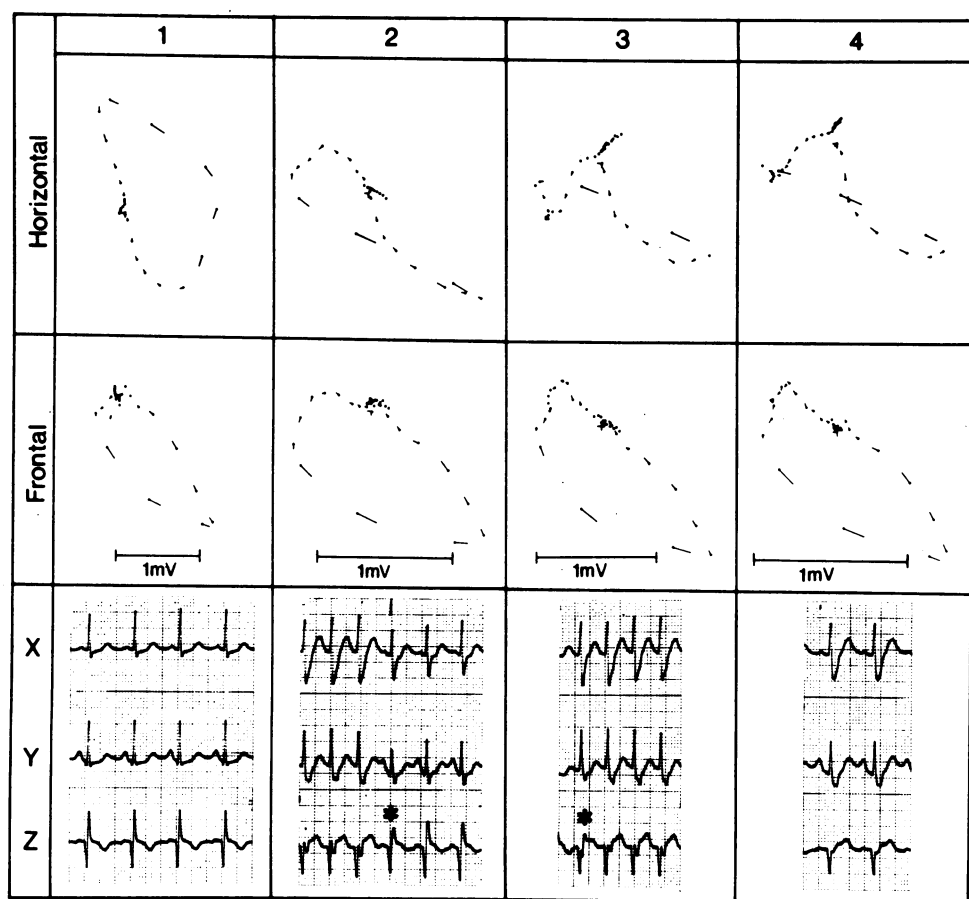


Fig. 1 Horizontal and frontal plane vectorcardiograms (above) and orthogonal (Frank) electrocardiograms (below) of a patient developing right bundle-branch aberration. Panel 1: Sinus rhythm, normal conduction. Panel 2: The first sinus complex* after the end of supraventricular tachycardia shows first degree right bundle-branch aberration with loss of midzone posterior forces and development of terminal delay on the right. Panel 3: Second degree right bundle-branch aberration during supraventricular tachycardia (the complex shown is marked by an asterisk). QRS is now directed almost totally anteriorly, the terminal delay on the right being rotated anteriorly. Panel 4: Sinus rhythm with third degree right bundle-branch aberration produced by catheter pressure: note anterior QRS with increasing terminal delay.

right bundle-branch aberration altered the direction of the frontal plane QRS complexes so that they became biphasic, and it was then impossible to determine the mean QRS accurately (Fig. 2). Usually the first 60 ms QRS forces were directed more superiorly and to the left than the normal complexes. In three patients, however, these forces were directed more inferiorly. These complexes may have shown right axis deviation because of an associated conduction defect, an isolated finding also seen in two of these patients.

Alteration of the initial forces of the QRS could occur with right bundle-branch aberration. Thus

in five patients increase of either the first or second 20 ms anterior forces occurred with the lesser degrees of right bundle-branch aberration (Fig. 3, panel 2; Fig. 4, panel 2). With increasing right bundle-branch aberration this increase of the first 20 ms anterior QRS forces was less obvious (Fig. 3 and 4, panel 3). In one patient, despite the return of normal initial anterior QRS forces with second degree right bundle-branch aberration, the QRS loop remained predominantly anterior and was unusual in that the crossover was eliminated (Fig. 4). It was followed by the development of a form of bundle-branch block not seen previously (Fig. 4,

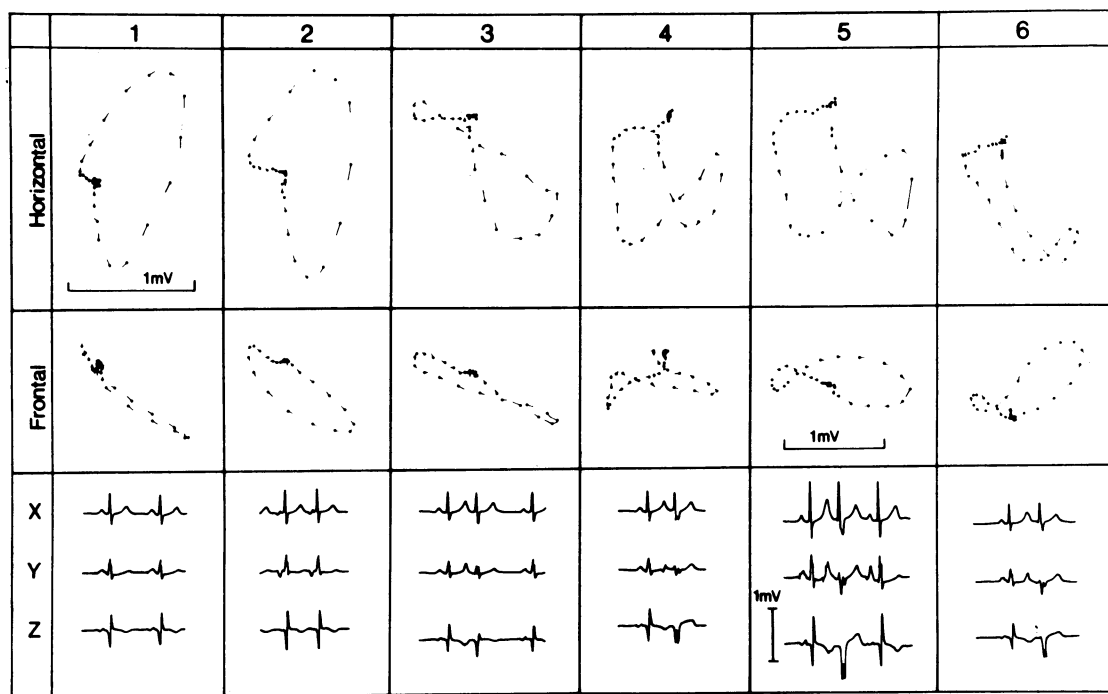


Fig. 2 Horizontal and frontal plane vectorcardiograms (above) and orthogonal (Frank) electrocardiograms (below) of a patient developing right bundle-branch aberration. Panel 1: Sinus rhythm, normal conduction. Panel 2: First degree right bundle-branch aberration. The terminal forces to the right are increased and are directed slightly superiorly: the first 40 ms anterior QRS forces are also increased. Panel 3: A premature atrial stimulus produces second degree right bundle-branch aberration. The loop is predominantly anterior because of loss of midzone posterior QRS forces; terminal forces are increased to the right and the QRS is biphasic in both planes. Panel 4: Third degree right bundle-branch aberration produced by a more premature atrial stimulus. The QRS is now almost totally anterior and biphasic. The crossover point has moved to the left; in the frontal plane the first part of the QRS is further left and the second part clearly directed to the right. Panel 5: A premature atrial stimulus produces third degree right bundle-branch aberration. There is multiformity of right bundle-branch aberration, that is this complex is of a different shape as compared with that shown in Panel 4. Panel 6: Second degree right bundle-branch aberration is associated with left axis deviation. The QRS is still biphasic in both planes, but less of the QRS is directed to the right. The QRS is almost totally anterior and the crossover point to the left, with less overlap than in right bundle-branch aberration alone.

panel 5), but which was also encountered in one patient in association with third degree right bundle-branch aberration alone. In both patients the tangential velocity of the initial anterior and subsequent posterior QRS forces was slower than normal; in the frontal plane QRS inscription was as slow as is seen in left bundle-branch block and the QRS loop was directed inferiorly and to the right. In the horizontal plane the loop was also directed posteriorly, with terminal delay to the right and slightly anteriorly as in right bundle-branch block. The QRS pattern in lead X or V6 was not obviously different from that in right bundle-branch block. Alteration of initial tangential QRS velocity was probably the result of an additional

significant left ventricular conduction defect.

Loss of initial anterior QRS forces was also common in association with third degree right bundle-branch block. It occurred after the first 20 ms forces in six patients and included the first 30 ms in three patients, leading to loss of initial counterclockwise inscription in the horizontal plane; the loop almost became clockwise but was only totally clockwise in one patient. There was an association between abbreviation of anterior QRS forces and at least transient left ventricular conduction defects.

Left bundle-branch aberration was initiated by extrastimuli in four patients and supraventricular tachycardia in six. Left bundle-branch aberration

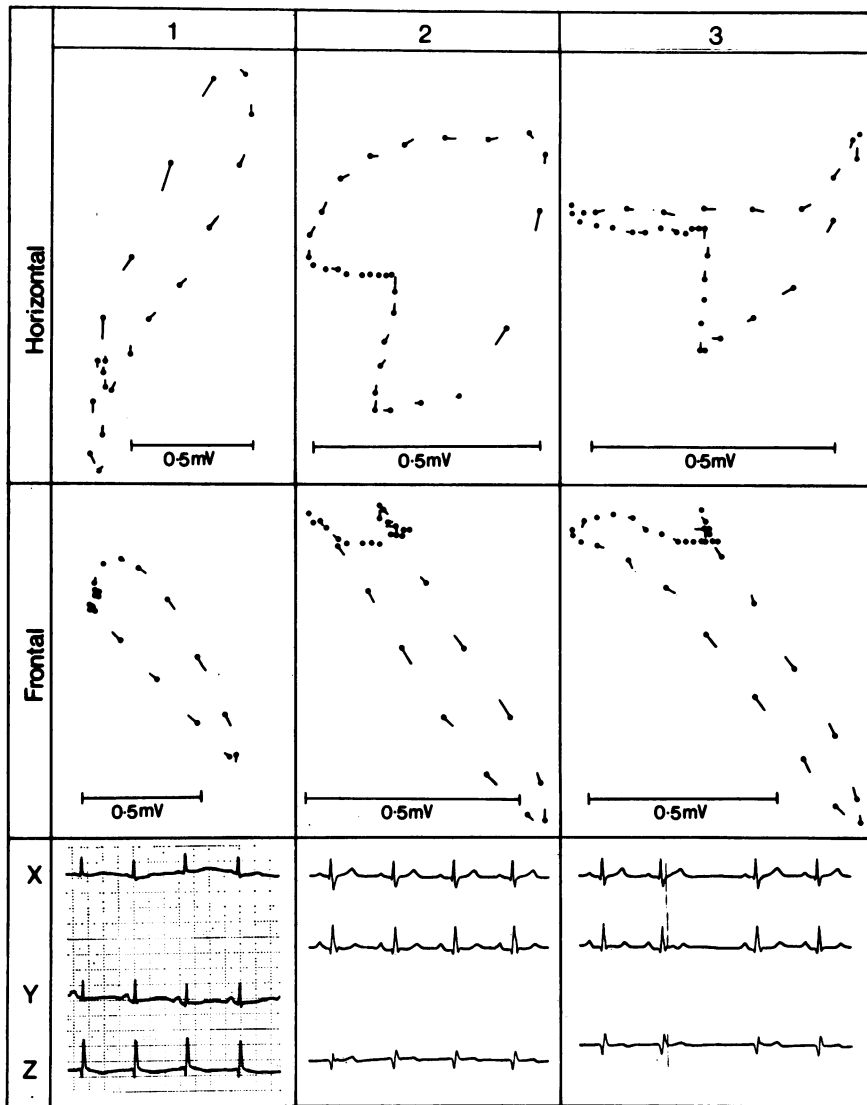


Fig. 3 Horizontal and frontal plane vectorcardiograms (above) and orthogonal (Frank) electrocardiograms (below) of a patient with right bundle-branch aberration. Panel 1: Sinus rhythm, normal conduction. Panel 2: First degree right bundle-branch aberration produced by catheter manipulation causes decreased midzone posterior QRS forces and slight increase of the second 20 ms anterior QRS forces. Panel 3: The sinus beat, following a pause after premature atrial stimulation, produced second degree right bundle-branch aberration with prominent terminal forces directed to the right. There is loss of posterior forces and reduction of the second 20 ms anterior forces.

was associated with loss of anterior forces in the horizontal plane (Fig. 5). In seven patients this affected the first 20 ms, six showing total loss of anterior forces; in three the loss of anterior forces was confined to the later part of the QRS and the direction of the initial 20 ms forces was unaffected. In all patients the frontal plane loop was small and

the velocity of inscription was very slow. The initial forces in these seven patients were directed more superiorly, as was the R point. Left axis deviation with left bundle-branch block, however, was only produced in six patients. Tangential velocity of inscription of both the first and second 20 ms QRS forces was reduced, but the tangential velocity of

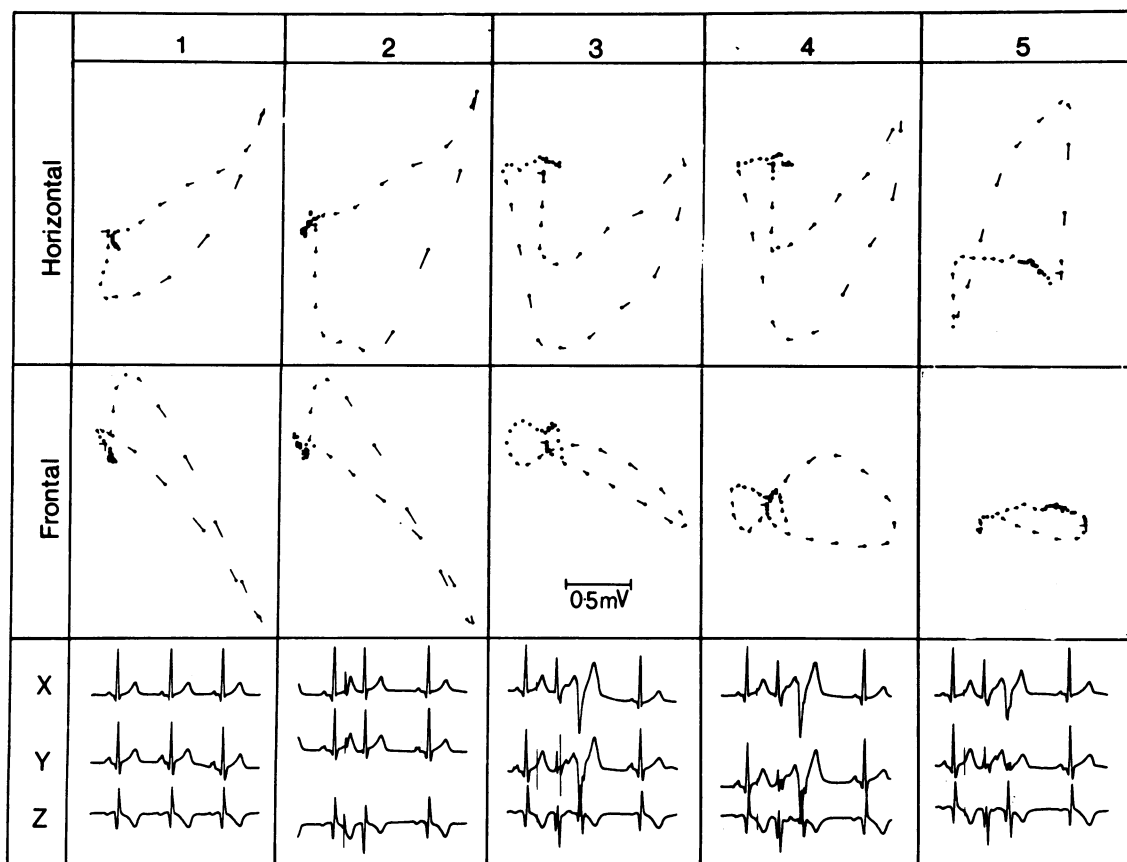


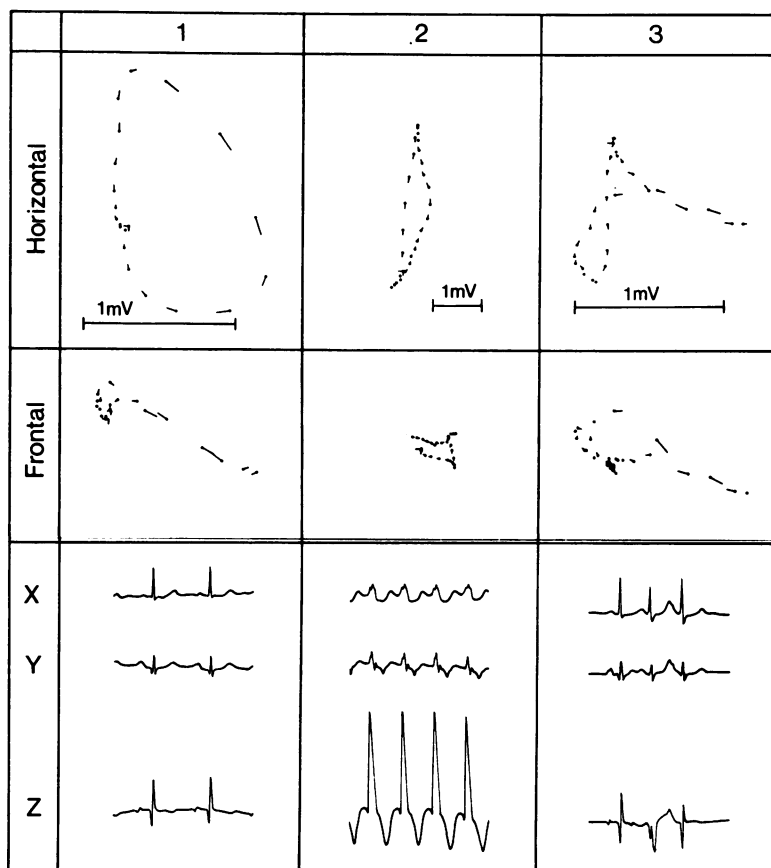
Fig. 4 Horizontal and frontal plane vectorcardiograms (above) and orthogonal electrocardiograms (below) of a patient with right bundle-branch aberration. Panel 1: Sinus rhythm, normal conduction. Panel 2: A premature atrial stimulus produced increased anterior QRS forces without loss of posterior forces. Panel 3: The first QRS complex after two consecutive atrial extrastimuli shows second degree right bundle-branch aberration. The midzone posterior QRS forces are reduced. The whole loop is swung anteriorly, but initially still remains counterclockwise. The prominent initial anterior forces have decreased. In the frontal plane the loop is obviously biphasic with some orientation of the first part to the left. Panel 4: Additional left axis deviation with right bundle-branch aberration of the first premature impulse. Panel 5: The second premature impulse shows extreme right axis deviation. Initial anterior forces are abbreviated and the loop lies on the left posterior quadrant; the terminal QRS is directed to the right and anteriorly.

the later forces, which are directed posteriorly, was always more than 10 mV/s in the horizontal plane. The QRS duration was 140 ms or more in all patients with left bundle-branch aberration, but in two patients there were similar QRS configurations albeit with a duration of 120 ms or less. Two patients also showed left axis deviation with other atrial extrastimuli. Seven patients had left bundle-branch aberration during tachycardia, but only one of these had such aberration with atrial extrastimuli, though two others had right bundle-branch aberration with atrial extrastimuli (Fig. 5).

Discussion

This study has clarified the QRS waveform of right and left bundle-branch block in patients investigated because of arrhythmias; there were only two patients with primary cardiac disease. Earlier studies have been based either on postoperative bundle-branch block or have included a large proportion of patients with cardiac disease.⁴ These authors described the vectorcardiographic features of aberrant conduction produced by premature atrial stimulation. Vectorcardiograms provide in-

Fig. 5 Horizontal and frontal plane vectorcardiograms (above) and orthogonal electrocardiograms (below) of a patient developing both right and left bundle-branch aberration. Panel 1: Sinus rhythm showing QRS changes of old inferior infarction. Panel 2: Left bundle-branch block develops during supraventricular tachycardia. Panel 3: A premature atrial stimulus produces third degree right bundle-branch block with preservation of initial counter-clockwise rotation in the horizontal plane despite a totally anterior QRS loop.



formation on ventricular excitation in all three planes, which is difficult to achieve by multiple electrocardiographic leads during programmed electrical stimulation or severe arrhythmias. Our study was based on vectorcardiograms and we included examples of aberration complicating supraventricular arrhythmias, atrial pacing, and induced atrial extrasystoles. We have identified important differences between aberration and ventricular arrhythmias.

The QRS waveform of pure, isolated third degree right bundle-branch block is easily explained.¹²⁻¹⁵ The right septal surface is excited 30 to 40 ms later than normal and right ventricular activity persists for 20 ms longer than normal so that the QRS duration is increased by 50 to 60 ms. Normally the sequence of depolarisation of the right ventricle is the apex, then the lateral wall, and finally the infundibulum. Thus in first degree right bundle-branch block only infundibular activation will be shown after the end of left ventricular excitation and the terminal QRS forces will be

directed superiorly to the right and either just posteriorly or just anteriorly; if conduction through the anterolateral wall is also sufficiently delayed, the terminal forces will be increased to the right and anteriorly. If activation of the right ventricular apex is also delayed the QRS forces will be directed even more anteriorly, but delay will be no more pronounced on the right, since the crossover point is moved to the left.

Septal activation normally takes 10 to 20 ms and proceeds from left to right and anteriorly so that the first 20 ms QRS forces are not affected by right bundle-branch block.¹² However, thereafter alteration of QRS forces may be caused by delayed septal depolarisation and/or prolonged right ventricular activation. Such changes could be expected in lesser degrees of right bundle-branch block, and increased anterior forces at this time may occur if such forces are not as effectively cancelled as with normal ventricular excitation. With an increasing degree of right bundle-branch block these septal and right ventricular forces will occur later, when

normal left ventricular depolarisation has directed the QRS more posteriorly, so that cancellation can occur. This concept is supported by the loss of posterior forces from the left ventricle in right bundle-branch aberration. Alterations of septal depolarisation produced by conduction defects and anatomical variations affecting the bundle-branch system might increase this tendency, and the electrical position of the heart in relation to the fifth intercostal space both before and after development of right bundle-branch block is also important.

With the development of right bundle-branch block the QRS loop usually becomes biphasic in the frontal plane with increased leftward forces for the first 60 ms, presumably because of loss of early rightward forces from the right ventricle. There may also be loss of anterior forces after the first 20 ms for the same reason but coincidental left ventricular conduction defects may account for this change. Because of the variable anatomy of the left ventricular conducting system¹⁶ one must expect many different combinations with right bundle-branch aberration producing differences in the morphology of the QRS complexes.

We were unable to divide right bundle-branch aberration into types with an anterior clockwise loop (type B) and a posterior counterclockwise loop (type A).¹³ Intermediate types were common and have been recorded before, but different authors have either classified type B as a predominantly clockwise loop whatever the direction of the initial 40 ms or have not clearly stated whether all the loop must be clockwise.^{4, 14} Totally anterior QRS loops appear to be most frequent in third degree right bundle-branch block though the counterclockwise rotation of the first 40 ms QRS forces is preserved. Transition to a totally clockwise loop only requires slight loss of anterior and rightwards forces and alteration in the superior and inferior position of the loop so that the crossover is eliminated. Since left axis deviation may reduce anterior forces directing initial forces less to the right, a totally clockwise loop may be more frequent when left axis deviation is associated with an anterior right bundle-branch block loop. Obviously other factors such as a small anterior infarct or left septal fibrosis could have the same effect. Our findings and those of Kulbertus *et al.*⁴ contradict the suggestion that an anterior QRS loop in right bundle-branch block is more frequent when there is also left ventricular disease.¹³ Not only do anterior right bundle-branch block loops not indicate right ventricular hypertrophy, but the midzone and later anterior forces negate posterior left ventricular forces and therefore mask electrocardiographic signs of left ventricular hypertrophy.⁵

The more posterior QRS loop often found in right bundle-branch block may result from associated left ventricular hypertrophy or alterations of electrical position with age, as the QRS loop is often more anterior below the age of 40 years than in older subjects.

The preservation of the normal direction of the initial 20 ms QRS forces in right bundle-branch aberration has important implications. Alterations of the second 20 ms QRS forces anteriorly or posteriorly are also important, however, since anterior infarction may affect either the first or second 20 ms QRS forces or both.⁵ It is therefore obvious that loss of the first 20 ms anterior forces still permits the diagnosis of anterior infarction in the presence of isolated right bundle-branch block; later loss of anterior forces interferes, however, with diagnosis. Anterior infarction may be concealed by increase of initial anterior forces, in keeping with our previous results⁵ and those of Goldman and Pipberger.⁷

The QRS waveform in left bundle-branch block was distinctive. There was diminution and sometimes total loss of initial anterior forces, initial forces being directed variably, presumably depending on the course of activation from the right. After the slow initial forces the main efferent limb of the QRS is directed posteriorly and is inscribed more quickly. The apex of the loop is inscribed more slowly but the end of the loop may be faster, perhaps because of excitation of His-Purkinje fibres. Though it is known that the QRS in left bundle-branch block is usually 10 to 20 ms longer than that of right bundle-branch block, we have seen QRS durations considerably less than 150 ms, particularly in supraventricular tachycardia complicated by aberration. Though incomplete left bundle-branch block could be defined in those who at other times showed complete left bundle-branch aberration, in some patterns of left axis deviation or loss of right antero-septal forces, one may see loss or diminution of Q waves in left-sided leads and lead Z (diminution of initial r wave in V1 and V2). We do not consider such changes diagnostic of incomplete left bundle-branch block alone.

The variety of minor changes of electrical axis in the frontal or horizontal plane could also be ascribed to left ventricular conduction defects caused by the variable anatomy of the left-sided conducting system¹⁶ but slight changes may only reflect alterations of anatomical position produced by variation in the duration of diastole. *We obtained no evidence for or against a distinct left ventricular conduction defect producing prominent anterior forces.* Prominent anterior QRS forces occur for several reasons, among which incomplete and

complete right bundle-branch block are important.

The first 20 ms QRS forces probably comprise normal left-to-right septal activation and the second 20 ms QRS forces are predominantly caused by normal left ventricular activation.¹² In left bundle-branch aberration tangential QRS velocity is reduced, especially in the frontal plane. In the horizontal plane there is initial delay of 20 ms or less before acceleration into the efferent limb of the QRS. In left bundle-branch block we have not seen an average tangential velocity of the QRS inscription in the horizontal plane of less than 10 mV/s affecting either the second 20 ms or total first 40 ms QRS forces. The direction of the QRS forces and the tangential velocity of inscription of the QRS are important differentiating features between aberrant conduction and ventricular arrhythmias.

Our studies of ventricular arrhythmias¹⁰ showed the following features that have not been observed in either right or left bundle-branch block: (1) a QRS loop totally directed into the left anterior quadrant; (2) more than 50 per cent of a left-sided QRS loop directed into the left anterior quadrant; (3) total anterior QRS loop with counterclockwise rotation (one cause of "Rr" or "R" patterns in V1); (4) slow inscription of the QRS loop, lasting more than 20 ms; (5) tangential velocity of inscription of any part of the first 40 ms of any spatial QRS loop resembling right bundle-branch block of less than 10 mV/s; (6) tangential QRS velocity in the horizontal plane less than 10 mV/s between the 20 and 40 ms vector points in examples of "left bundle-branch block complexes".

Right bundle-branch aberration is characterised by a biphasic QRS, particularly in the horizontal plane. Thus notching of the QRS in V1 and V2 or lead Z is diagnostic; lesser changes may be deceptive and a deep S wave in V5 or V6 is not diagnostic. Total clockwise anterior loops in the horizontal plane, that is loss of the initial counterclockwise loop, occur in ventricular arrhythmias and appear to be rare in right bundle aberration alone. These loops also produce R waves in V1, which are usually monophasic but may show a notch or a slur on the upstroke. This feature and the accuracy of lesser abnormalities of tangential QRS velocity become more accurate if the normal QRS contour is known. There are other less significant features of ventricular arrhythmias: inferior or rightward orientation of ventricular extrasystoles is common¹⁰ but this is infrequent in uncomplicated right and left bundle-branch aberration; increased maximum spatial QRS voltage so that large QRS complexes are found in both frontal and horizontal planes; monophasic QRS loops are suggestive of ventricular

arrhythmias unless they are directed into the left posterior quadrant as may occur with left bundle-branch block aberration.

We must, however, stress that while most ventricular arrhythmias can be distinguished from supraventricular arrhythmias with aberrant conduction, this is not always possible; in particular, ventricular arrhythmias may be indistinguishable from atrial fibrillation in the Wolff-Parkinson-White syndrome.

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